

**NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2005
NNH05ZDA001N
A.6 North American Carbon Program**

The National Aeronautics and Space Administration (NASA) solicited proposals to address North American Carbon Program (NACP) goals to:

- Develop quantitative scientific knowledge, robust observations, and models to determine the emissions and uptake of carbon dioxide (CO₂), methane (CH₄), and carbon monoxide (CO), changes in carbon stocks, and the factors regulating these processes for North America and adjacent ocean basins;
- Develop the scientific basis to implement full carbon accounting on regional and continental scales, which is the knowledge base needed to design monitoring programs for natural and managed CO₂ sinks and emissions of CH₄; and to
- Support long-term quantitative measurements of fluxes, sources, and sinks of atmospheric CO₂ and CH₄, and develop forecasts for future trends.

NASA also requested proposals to address closely related objectives of the Ocean Carbon and Climate Change Program (OCCC), an integrated, multi-agency program for oceanic research aimed at addressing oceanic carbon cycling issues as well as how climate change will affect the future behavior of the oceanic carbon sink. NACP and OCCC program interests and objectives converge in addressing carbon exchange between the atmosphere and oceans adjacent to North America and land-sea interactions in the coastal regions of North America.

The following types of investigations were solicited to address North American Carbon Program and related Ocean Carbon and Climate Change goals:

- Integrated analysis of regional, continental, and/or adjacent ocean basin data directed toward quantifying the carbon budget of North America, including sources and sinks for atmospheric CO₂, CH₄, and CO; recent changes in carbon cycling dynamics; and the underlying processes and mechanisms involved. Studies of interest included:
 - Continental-scale synthesis using the best data and models currently available to quantify the contemporary North American carbon budget and associated errors and uncertainties;
 - Research using the available remote sensing data record to characterize and quantify the effects on carbon dynamics of landscape changes across North America, including urban areas and recent development, intensive land management, vegetation disturbance and recovery patterns, and high latitude ecosystems; and
 - “Bottom-up” analyses integrating in situ, inventory, and satellite data for the NACP Mid-Continent Intensive Campaign region in order to create independent estimates of carbon stocks and fluxes over the study region that can be reconciled with “top-down” estimates derived from atmospheric measurements and inverse model solutions.
- Satellite remote sensing studies focusing on the North Atlantic and North Pacific Oceans and coastal zones adjacent to North America that address strong interactions among the land, ocean, and atmosphere as well as climate impacts and feedbacks on the ocean carbon system. Specific topics and activities of interest included:

- Natural versus anthropogenic changes in CO₂ concentrations in the coastal ocean;
- The magnitude and variability of air-sea CO₂ fluxes; and
- Technical development, synthesis, and modeling using already existing data, and process studies at existing time series or coastal locations.
- Research that integrates natural and social science approaches and makes effective use of remote sensing data to improve understanding of continental-scale fossil fuel emissions; land use and management decisions and their effects, including coastal and urban regions; or carbon transport by human activities.
- Within NASA's Applied Sciences Program, extending the use of NASA measurements, observations, and models applied in projects related to the NACP to enhance decision support tools used by entities with operational mandates to measure, monitor, and/or manage sequestration of carbon.

In addition to these types of investigations, NASA also requested proposals to establish a thematic data center to support modeling and synthesis within the North American Carbon Program.

NASA received a total of 79 proposals, and 12 have been selected for funding. The total funding to be provided for these investigations is \$9 million over three years. In order to align NASA Research and Analysis programs with FY2006 and FY2007 (proposed) budgets, the start dates for some awards may be delayed until January 2007. The investigations selected are listed below. The Principal Investigator, institution, investigation title, and a project summary are provided. Other co-investigators are not listed here.

William Balch / Bigelow Laboratory for Ocean Sciences
"GNATS", the Gulf of Maine North Atlantic Time Series: Integrating Terrestrial and Ocean Carbon Cycles in A Coastal Shelf Sea Through Coordinated Ship and Satellite Observations

The Gulf of Maine (GoM) is a highly productive shelf sea that constitutes a large part of the N.E. US Continental Shelf. We have run a time series across the GoM for the last 8 years known as "GNATS" (Gulf of Maine North Atlantic Time Series). It consists of monthly, cross-Gulf sampling on ships of opportunity, during clear-sky days, so that we are assured concurrent measurements from ship and satellite (ocean color, SST). The power of this strategy is seen in our 95% success rate for being at sea during clear, high quality overpasses (randomly, one would expect a success rate of ~10% due to the GoM cloud climatology). We then can extrapolate our large shipboard data set of carbon cycle parameters to regional scales using synoptic remote sensing. GNATS includes a suite of carbon-specific standing stocks and rate measurements (e.g. POC, PIC [calcite], DOC, primary productivity, and calcification) plus hydrographic, chemical and optical measurements. Through coordinated ship/satellite measurements, we can constrain the major carbon production terms of the Gulf, follow their monthly variation using synoptic remote sensing, and regionally tune satellite algorithms. GNATS documents not only marine carbon pools, but it includes carbon supplied from the terrestrial watershed; this is why the Gulf is optically-dominated by Case II waters. We propose to A) continue

GNATS, coordinated ship and satellite measurements for another 3 years, B) provide monthly, regional estimates of the standing stock and production terms for the various particulate and dissolved carbon fractions based on satellite ocean color observations and C) perform a statistical comparison of photoadaptive parameters in the Mid-Atlantic Bight and GoM to examine how broadly we can extrapolate these results along the NE U.S. Continental Shelf. Deliverables of this work will be: ship-based quantification of the various components of the carbon cycle in the GoM (standing stocks of POC, PIC, DOC plus primary production/calcification rates), an improved DOC algorithm, tuning of satellite carbon algorithms for the NE Continental Shelf, and documentation of the long-term biogeochemical and ecological changes occurring in the GoM carbon cycle. Quantification of the variability in the composition and concentration of dissolved and particulate carbon over a wide range of temporal and spatial scales is the first step towards understanding the role of coastal ecosystems in the global carbon cycle.

George Collatz / NASA GSFC

Impacts of Disturbance History and Climate on Carbon Fluxes from North American Forests: Application of Satellite, Inventory, and Climate Data to Inform Biogeochemical Modeling.

We propose to estimate carbon fluxes from the North American continent taking into account 30 years of climate and disturbance history. Our approach is to utilize the forest age and biomass results based on time series Landsat and FIA data developed by a currently funded NASA Carbon Cycle Science Project (North American Forest Disturbance and Regrowth Since 1972, PI: S. N. Goward). Dense time series data for a number of forested scenes (>25) in the US and Canada will be used to initialize and calibrate a biogeochemical model that predicts gross and net carbon fluxes. Model testing will include appropriate Ameriflux, LTER, NACP Tier 2, and FIA data. Climate variability (temperature, precipitation, solar radiation) will also be included in the analysis. Then using less temporally dense satellite data but wall to wall continental coverage, the modeling will predict gross and net carbon fluxes resulting from disturbance history and climate for the forests of North America. The products of this study will be used by our collaborators as boundary conditions for atmospheric transport (forward and inversion) models. By reconciling top-down (atmosphere) and bottom-up (biogeochemistry) analyses of the net fluxes we will be able to estimate accuracy and uncertainty in our model results.

Robert Cook / Oak Ridge National Laboratory
NACP Data Center for Modeling and Synthesis

The North American Carbon Program (NACP) is designed to quantify the magnitudes and distributions of carbon sources and sinks, explain the processes controlling them, and produce a consistent analysis of North America's carbon budget. To accomplish these ambitious goals, NACP requires an integrated data and information management system that will enable researchers to access, understand, use, and analyze large volumes of diverse data at multiple thematic, temporal, and spatial scales. In response to a NASA solicitation for proposals to contribute to NACP, we are proposing to establish a

Modeling and Synthesis Thematic Data Center (MAST-DC) to be an integral component of the NACP data system and to support NACP by providing data products and data management services needed for modeling and synthesis activities. The overall objective of the proposed MAST-DC is to provide advanced data management support to NACP investigators and agencies performing modeling and synthesis activities. Based on specific requirements established by NACP, we will provide data products for modeling and synthesis in consistent and uniform grids, projections, and formats. The specific tasks of the proposed MAST-DC are (1) coordinate data management activities with NACP modelers and synthesis groups; (2) prepare and distribute model input data; (3) provide data management support for model outputs; (4) provide tools for accessing, subsetting and visualization; (5) provide data packages to evaluate model output; and (6) support synthesis activities, including data support for workshops. MAST-DC will provide data products and services required by NACP in a central location, with common and co-registered spatial projection, in easily converted formats. The MAST-DC will free modelers and those doing the synthesis and integration from having to perform data management functions. Consequently the MAST-DC will enable NACP participants to conduct their work more readily, facilitate the development of new model products needed by models, and assist in gaining new insights into the carbon cycle in North America.

Richard Houghton / Woods Hole Research Center
Sources and Sinks of Carbon from Land-Use Change, Management, and Disturbance in the U.S.: Steps Toward a Synthesis

A previous analysis by the principal investigator estimated the annual flux of carbon for the U.S. with census-based data on changes in land use, forestry, and fire management. The estimated sink in forests was low compared with studies based on data from forest inventories, but there were a number of processes omitted from the historical analysis. A reanalysis is warranted. The conterminous U.S. is a particularly good region for a detailed historical reconstruction because of the unusually rich assortment of historical data available. Landsat data on disturbance, available since 1972 offer a second data set, independent of census-based reconstructions of land-use change, for calculating sources and sinks of carbon during recent decades. These Landsat data are currently being compiled under on-going NACP projects. This proposal seeks support (1) to update the historical analysis based on census data and (2) to use the recent data compiled from the NACP Landsat analyses (3) to calculate two independent estimates of carbon flux for the conterminous U.S. over the period 1972-2000. Differences in the estimates of carbon flux (census-based versus Landsat-based) will reveal strengths and weakness of the two approaches and will be used to construct a “harmonized” estimate of carbon flux more accurate than possible from either approach by itself. For example, changes in land use obtained from the Landsat record miss disturbances before 1972 and thus underestimate both the area of recovering forests and the carbon accumulating in them. On the other hand, changes in land use based on census data (agricultural and forestry statistics) miss important processes affecting carbon storage (for example, natural disturbances). The overall objective of the proposed research is to determine the annual net flux of carbon for terrestrial ecosystems of the conterminous U.S. The emphasis will be on forests and

will include the effects of forest conversion to agricultural land, abandonment of agricultural land, harvest of forests, other forms of forest management, wildfires, other disturbances, and forest growth. The approach will use an improved carbon model with two independent data sets of land-use/cover change: one, historical census data; the second, recent Landsat data. Model results will be tested against SRTM-derived estimates of aboveground biomass (from another on-going NACP project). The results of the proposed research are expected to contribute significantly to NASA's goals in at least two respects. First, the research will produce a new estimate of carbon flux for the conterminous U.S. The estimate will be spatially specific, based on a harmonization of historical, census data and Landsat data. The results will include an evaluation of the error of the estimated flux, including the effect of spatial resolution on error. Second, the research will produce a spatial/historical (1700-2005) data set of land-use change for the forests of the U.S.

Eric Kasischke / University of Maryland College Park
Remote Monitoring of Changes in Forest Functional Types after Disturbance from Fire in the North American Boreal Region--Implications for Interpreting the Effects of Satellite-Observed Changes in Vegetation Greenness on the Terrestrial Carbon Budget

A three year research proposal is presented with a goal to both map and gain a better understanding of the factors controlling transitions between black spruce and deciduous forests/parklands/grasslands that occur at decadal scales during succession after fires in the North American boreal region (NABR). Black spruce forests function as a major terrestrial carbon reservoir in the NABR, represent > 50% of the forest cover in this region, and can be thought of as a distinctly different forest functional type than the deciduous forests found in this region because they contain deep organic layers. In particular, our study will focus on the linkage between fire, climate and changes in post-fire successional processes that lead to converting spruce forests to deciduous forests. Our research will focus on addressing the following hypothesis: transitions from black spruce to alternative forest/non-forest functional types are controlled by variations in (a) post-fire organic-layer depth (surface burn severity), (b) soil moisture (affected by precipitation and site drainage); (c) soil temperature (affected by organic layer depth, elevation, and aspect); and (d) seed-source availability (distance to nearest deciduous tree seed source--dispersal distance). The research will be carried out by an interdisciplinary research team from the Universities of Maryland and Alaska and General Dynamics, with all the members having extensive significant research experience in the NABR. In this study, we will use MODIS and Landsat TM/ETM imagery to analyze and map different trajectories of post-fire succession in forest stands in Alaska/Yukon Territories in areas that burned between 1970 and 1999. We will use Landsat TM imagery to map pre-fire forest cover and to estimate burn severity. We will use imaging radar data from ERS, ENVISAT, and Radarsat to estimate variations in post-fire soil moisture. Field studies will be used collect data to validate the remotely sensed data and collect additional observations on site characteristics where different patterns of post-fire succession occurs. Finally, using the data collected during this study, as well as field data collected by a CO-I under a Joint Fire Science Project and by Collaborators at sites being studied

by the National Park Service and through the Bonanza Creek LTER, we will develop a conceptual model to link the satellite observations to the processes which are controlling post-fire succession. The results from this study will provide a clearer understanding of how satellite imagery can be used to study patterns of post-fire succession and carbon cycling in the NABR region. These results will enable scientists involved in the North American Carbon Cycle Science program to more clearly interpret the changes in vegetation greenness that have been observed in the NABR through examination of the longer term satellite record based on AVHRR imagery. Finally, the results from this study will be important in improving models of terrestrial carbon cycling because they will provide an improved understanding of the factors that lead to transitions between two important forest functional types found in the NABR.

Ira Leifer / University of California, Santa Barbara

Remote-Sensing Methane Emissions: Field-Validation with Seepage from Marine, Urban, and Submerged-City Sources

Although CH₄ is at least 20 times more potent to greenhouse warming than CO₂, its sources are poorly constrained. Remote sensing can improve atmospheric CH₄ budgets by allowing measurements at multiple scales with standardized measures and repeat sampling. However, improvements in spatial resolution are necessary to validate satellite-derived CH₄ measurements of sources with sub-regional scale variability. Equally important, is the lack of ground-referenced data. We propose marine hydrocarbon seeps can ground reference remote sensing CH₄ data determining limitations and abilities of current and next generation remote sensing platforms. Marine hydrocarbon seeps provide an ideal natural laboratory for this validation, due to the sea surface's relative spectral uniformity, the locality of the seeps, their clear identification (visual and sonar), the wide diversity of source strengths and intensity, and the freedom of movement (no obstacles) on the sea surface. Total field emissions are ~ 100 moles s⁻¹, thus the downwind plume should be satellite observable (e.g., SCIAMACHY, etc.). We demonstrated in a proof of concept study in the Coal Oil Point seep field that remote sensing techniques and AVIRIS sensitivity in particular could measure methane emissions. Recent studies indicate geologic CH₄ is significant but poorly constrained due to a lack of data. Seeps are particularly common in oil producing basins (Gulf of Mexico, Gulf of Alaska, S. California) and interior areas (Texas, Wyoming). Also, CH₄ remote sensing will aid in areas beyond climate change such as homeland defense and disaster mitigation. We propose to identify the feasibility and limitations of current (AVIRIS) and next generation, remote-sensing technology for detection and quantification of CH₄ fluxes. This study uses the wide range of seep strengths and intensities in the Coal Oil Point (COP) seep field as ground-reference data. The technique will be ground-referenced in an urban aqueous seep, the La Brea Tar Pits, and then applied to AVIRIS images acquired during the flooding of New Orleans. Only remote sensing can provide continent scale methane emission data; this study provides the validation. Other benefits include quantification of natural seepage and a technique that will aid homeland defense and disaster mitigation. Disasters, natural or otherwise, can lead to massive releases of methane from natural gas pipelines, presenting a hazard to rescue workers and requiring costly repairs.

Kyle McDonald / Jet Propulsion Laboratory
Satellite Monitoring of Landscape Freeze-Thaw State and Associated Constraints to the North American Carbon Budget

This proposal addresses the component of this NRA soliciting integrated analysis of regional and continental data for quantifying the carbon budget of North America, including sources and sinks for atmospheric carbon. This investigation will address the North American Carbon Program (NACP) goals for determining the emissions and uptake of atmospheric carbon and the factors regulating these processes for North America. The investigation will encompass the entire North American landmass with the specific objective of developing critical datasets and understanding of the major environmental drivers and biophysical responses regulating spatial patterns and temporal variability in terrestrial carbon budgets in support of the NACP. Approximately 68-80 percent of the North American region experiences seasonal freezing and thawing with the relative influence of these processes on terrestrial carbon budgets generally increasing at higher latitudes and elevations. The timing and duration of surface and soil freeze-thaw state is closely linked to vegetation phenology and growing season dynamics in northern temperate, sub-alpine, boreal and arctic biomes. Variability in these environmental variables also has been shown to have dramatic impacts on spatial patterns, seasonal to interannual variability and long-term trends in terrestrial carbon budgets and surface-atmosphere trace gas exchange primarily through biophysical controls on both photosynthesis and respiration. These processes are strongly influenced by land cover and soil properties, as well as the timing and condition of regional snow cover. We will exploit satellite active microwave remote sensing capabilities for monitoring land surface thermal and associated moisture dynamics and the global all-weather and high-repeat monitoring capabilities of the SeaWinds Ku-band scatterometer to quantify spatial patterns and daily, seasonal and interannual variability in landscape freeze-thaw status. We will investigate synergistic relationships and trade-offs in relative sensitivity, spatial scale and temporal monitoring capabilities between SeaWinds freeze-thaw and MODIS LST products for quantifying landscape freeze-thaw state and thermal and moisture controls to vegetation gross primary production (GPP) and net primary production (NPP). We will quantify the spatial and temporal patterns of these variables and determine their relative importance in determining seasonal patterns and annual variability in vegetation productivity using a modified form of the MODIS MOD17 algorithm. We will also establish linkages between the microwave based freeze-thaw signal and surface biophysical network measures of the surface energy budget and associated linkages to soil respiration and land-atmosphere CO₂ exchange dynamics. We will closely integrate our research, findings and critical datasets within the larger NACP project to provide a comprehensive assessment of the North American carbon budget.

Anna Michalak / University of Michigan

Constraining North-American Fluxes of Carbon Dioxide and Inferring Their Spatiotemporal Covariances through Assimilation of Remote Sensing and Atmospheric Data in a Geostatistical Framework

This project will address the NACP's stated goals of (i) developing quantitative scientific knowledge, robust observations, and models to determine emissions and uptake of CO₂ [...] and the factors regulating these processes, in North America and (ii) developing the scientific basis to implement full carbon accounting, including natural and anthropogenic fluxes of CO₂ [...] on regional and continental scales (Denning et al. 2005). The overall goal of the project is to use remotely-sensed and atmospheric data in a geostatistical inverse modeling framework to quantify the North-American surface fluxes of CO₂ for two years (2004-2005) with unprecedented spatial and temporal resolution. The seven main steps of the study needed to achieve this goal are: (1) to develop a database of remote-sensing datasets related to carbon cycling, (2) to improve the representation of atmospheric transport for regional-scale inversions by generating mass-conserving wind products, quantifying vertical transport errors, and using this information to run the STILT atmospheric model, originally designed to extract information on the influence of surface processes from atmospheric observations in the midst of strong, highly-varying fluxes, (3) to assess and compile atmospheric data to be used in the inversions, primarily continuous measurements taken at tall-tower sites, (4) to calculate influence functions to quantify the sensitivity of atmospheric data to underlying fluxes, using STILT, (5) to extend geostatistical techniques for application to regional inverse modeling, including methods for incorporating both spatial and temporal flux correlations and error covariances, and statistical techniques for testing the influence of auxiliary data on fluxes as seen by atmospheric data, (6) use geostatistical inverse modeling to estimate fluxes over North America and the influence of auxiliary environmental data on these fluxes on several timescales ranging from the diurnal cycle to monthly averaged estimates, and (7) to disseminate research results to the NACP and broader scientific community. We intend to achieve this goal without relying on prior flux estimates, while rigorously quantifying the magnitude and spatiotemporal covariance of the various components of model, measurement, and flux errors. In addition, we will evaluate the sensitivity of the inferred fluxes to available remotely-sensed environmental datasets, providing the process-based understanding needed to improve bottom-up inventories and biospheric models, thereby enabling more accurate flux accounting.

William Miller / University of Georgia

Using Ocean Color to Quantify the Significance of Marine Photochemistry to CO and Carbon Cycling in the South Atlantic Bight

Objective: To quantify the significance of solar-induced photochemical reactions on carbon cycles, CO₂ and CO exchange in the South Atlantic Bight (SAB) using ocean color data. Background: Coastal waters have been viewed as net sinks for atmospheric CO₂. New data on the SAB, however, show it to be a net source for atmospheric CO₂ (Cai & Dai, 2004 Science, 306:1477). The overall role of coastal oceans in CO₂ exchange is uncertain and may vary with latitude. The fate of dissolved organic carbon

(DOC) in coastal waters is controlled by bacterial and photochemical processes, both resulting in CO₂ production. Exposure of colored dissolved organic matter (CDOM) to sunlight directly produces CO, CO₂ and a myriad of small organic compounds that can alter microbial production. This complex situation is difficult to quantify as to the overall significance of photochemical reactions on large-scale carbon cycles. Preliminary calculations using SeaWiFS data and limited photochemical data estimate that in the SAB ~1/3 of the CO₂ flux and up to 40% of DOC turnover may depend on photochemistry. Methods: We will combine satellite and photochemical data to assess the significance of carbon-related photochemical reactions in North American coastal waters, concentrating on the SAB. Our new optical model (SeaUV; Ocean Optics XVII, 2004) uses principal component analysis of ocean color data (aircraft, SeaWiFS/MODIS) to estimate in situ spectral UV downwelling attenuation (K_d) and UV absorbance by CDOM, the driver for virtually all marine photochemistry. Our algorithms were developed using a wide range of water-types, were verified using both Hydrolight modeling and SeaWiFS match-up analysis (SeaBASS archive), and significantly improve remote estimates for UV light fields in seawater. Using spectral UV irradiance fields and aCDOM from SeaUV (MODIS/SeaWiFS) we will construct depth-resolved surface ocean maps for CO/CO₂ photoproduction and photoinduced changes in biologically labile products (BLPs) using spectral quantum yield (QY) and satellite optical data. Regional scale coastal calculations are severely limited by the lack of photochemical QY data reflecting spatiotemporal variability. Credible QY data are available for CO, rare for CO₂, and from one study for BLPs. We will use multispectral laboratory irradiations of samples from seasonal transects and shore stations to quantify QY variations in the SAB. These new data will provide greatly improved estimates of carbon fluxes in the SAB. We will also expand estimates using SAB QY data to available in situ data from other North American coastal systems to examine the general validity of this approach. Significance: This project supports the NACP and OCCC goals of developing "quantitative scientific knowledge, robust observations, and models to determine the emissions and uptake" of CO₂ and CO in ocean basins adjacent to North America. CO & CO₂ dynamics will be addressed together using ocean color and in situ studies.

Ramakrishna Nemani / NASA Ames Research Center
Diagnostic and Prognostic Analyses of Ecosystem Processes for NACP Using
Surface Climate, Satellite Data and Simulation Models

The goal of this research proposal is to use the Terrestrial Observation and Prediction System (TOPS), a data and modeling system developed with funding from NASA's technology investments, to perform prognostic and diagnostic analyses of ecosystem processes over the NACP domain. TOPS integrates surface climate, satellite data and simulation models to estimate carbon, water and nutrient fluxes at a variety of spatio-temporal extents and resolutions. TOPS currently produces daily evapotranspiration, soil moisture, gross and net primary production and net ecosystem production at 8km resolution over the U.S with limited verification/validation. The first of the three tasks proposed to accomplish the project goal is to extend TOPS over the entire domain of the NACP by improving the spatial resolution from daily 8km to daily 4km and higher (e.g. 1km) where necessary. The second task consists of developing a framework for scaling

ecosystem fluxes observed at tower sites to regional scales using the concept of phenoregions, regions of similar growing season dynamics. These phenoregions will provide the underlying framework for comparing model outputs against both tower fluxes and with satellite-based observations of growing season dynamics (freeze/thaw, snow cover and leaf area index). Phenoregions will be defined by clustering the seasonal variations in satellite-derived vegetation index and surface temperature data (proxies for photosynthesis and respiration). The third task is to characterize uncertainty in the estimated fluxes resulting from variable inputs and spatial resolution. In addition to supporting the proposed research, our assimilation system will be able to serve the NACP community by providing a variety of satellite data products, model inputs, and model outputs. The proposed research leverages current and past NASA investments in algorithm and model developments, and makes comprehensive use of Earth Observing System data for understanding terrestrial carbon cycling.

Steven Wofsy / Harvard University

Integrated Analysis of Regional and Continental Carbon Budgets for CO₂ and CO in North America, Using Data from Remote Sensing, from Stations Measuring Concentrations and Fluxes, and Other Sources

We propose to provide the essential elements for deriving continental-scale carbon budgets for North America, and to obtain accurate carbon budgets on a pilot basis for large areas of North America. 1. We will complete our successful program to develop a Model-Data Fusion Framework (MDFF) for determining regional/continental fluxes for CO₂. It is based on a new remote-sensing driven surface flux model, the Vegetation Photosynthesis and Respiration Model (VPRM) and on our high-resolution atmospheric adjoint model, the Stochastic Time-inverted Lagrangian Transport (STILT) model. The VPRM ingests vast quantities of data to produce prior CO₂ fluxes of demonstrated high accuracy, while retaining an ultra-simple structure that allows direct incorporation into the adjoint and parameter inversion framework. STILT allows us to capture near-field influences as signal, rather than noise. The VPRM a priori fluxes, using mesoscale meteorological drivers, and STILT transport, reproduce aircraft and ground station data with remarkable fidelity. The a priori parameters of the VPRM will be optimized using integral constraints from concentrations observed at surface stations and by aircraft. We will 2. rigorously test the MDFF and 3. demonstrate its application by obtaining carbon budgets for the Northeast (New England, Quebec) for several annual cycles, for transects across N. America in summer 2003, and for the upcoming Mid-continent Intensive of the NACP. 4. We will deliver rigorous error analysis, including transport errors and spatiotemporal covariance of errors obtained from actual field data, using state-of-the-art data assimilation techniques (e.g. Bayesian Optimization and Ensemble Kalman Filter). 5. A new application of GLAS spaceborne LIDAR will be used to incorporate ecosystem structure (correlated with stand age and site index) into the VPRM for carbon budget analysis. 6. The Ecosystem Demography model (ED2), an age- and height-structured dynamic vegetation and ecosystem model that has been coupled to RAMS and STILT, will be adapted for North America. ED2 will be constrained by forest and other land inventories, eddy flux data, remote sensing constraints, and GLAS data. ED2 will provide the capability of assessing multi-way coupling between climate, land management, and

carbon cycle, for decision support. Applications of ED2 will include assessment of long- and short-term effects of recent intense hurricanes and droughts on regional (S. E. and S. W., respectively) C budgets; 7. Our software and databases are 100% open source and will be publicly available (as they already are), including everything needed to support the growing community of outside users of this framework.

Tingjun Zhang / University of Colorado at Boulder
Impacts of Soil Freeze/Thaw Dynamics on the North American Carbon Cycle

We will integrate remote sensing data sets, ground-based measurements, and numerical modeling to quantify the effects of soil temperature, soil freeze-thaw dynamics, and snow cover on seasonal to inter-annual variability in the North American terrestrial carbon cycle. Our overall goal is to understand the role of freeze-thaw processes in determining seasonal and inter-annual variability in terrestrial biomass, photosynthesis, respiration, and net CO₂ fluxes over continental North America. Using remote sensing products, in situ observations, and a soil thermodynamic model, we will estimate soil temperatures and snow cover over North America at 25-km resolution for North America from 1981-2003 (23 years). We will feed these estimated soil temperatures and snow cover, along with additional remote sensing data, into an ecosystem model to estimate biomass and net carbon fluxes. Both models will use the North American Regional Reanalysis, so the resulting estimates of soil thermodynamic properties, biomass, and carbon fluxes will be optimally consistent with each other and with actual weather conditions in North America. We will statistically analyze these optimal carbon fluxes to understand the environmental drivers and biophysical responses regulating the spatial patterns and temporal variability in the North American terrestrial carbon cycle. Using standard Monte Carlo techniques, we will quantify uncertainty in our estimated carbon fluxes. Lastly, we will perturb our input data to assess the sensitivity of our estimated fluxes to long-term climate change. Our research addresses the North American Carbon Program (NACP) goals of reducing uncertainty about the buildup of greenhouse gases in the atmosphere and the dynamics of the carbon cycle. Specifically, we address the NACP goals of 1) quantifying the magnitudes and distributions of terrestrial carbon sources and sinks within North America; 2) understanding the processes controlling carbon source and sink dynamics; and 3) producing consistent analyses of the carbon budget of North America, explaining regional contributions and year-to-year variability. We will archive data products generated by this investigation at the National Snow and Ice Data Center's Frozen Ground Data Center for access by other NACP investigators and for general use by the scientific community.